

Illumination of Young Stellar Disks

K. Robbins Bell

The planets in our solar system formed from a gaseous disk known as the solar nebula. Disk-shaped nebulae thought to be analogous to the solar nebula are now commonly observed around solar mass stars younger than a few million years in nearby regions such as the Taurus-Auriga molecular cloud and the Orion Nebula. Images of these disks are obtained with facilities such as the Hubble Space Telescope; spectra are obtained with the Infrared Astronomical Observatory and various ground-based observatories such as the Keck Telescope on Mauna Kea on the island of Hawaii. Studying these systems provides insight into the development of our own planetary system as well as clues into the likelihood of the evolution of similar life-bearing systems around other stars.

The collapse of a molecular cloud core leads to the formation of a protostellar system composed of a star and a circumstellar disk. Probably 10 to 50% of the final mass of the star is accreted in the initial collapse, which occurs on a dynamical time scale of several tens of thousands of years. Gravitationally induced spiral arms rapidly transport much of the remaining nebular mass inward onto the central protostellar core. At the end of perhaps a hundred thousand years, the system will consist of a central protostar that is slowly contracting and radiating away its excess gravitational energy; it will be surrounded by a disk of remnant material with a mass no greater than one quarter of the mass of the central star. This gaseous disk persists for several million years, during which time it is slowly depleted by accretion onto the central object, dispersal by stellar wind and radiation, and planet formation.

Infrared radiation from these systems can be analyzed to determine the temperature profile of the disk surface. These disks have three major heat sources: heating due to the local release of gravitational energy by material slowly spiraling inward toward the central star; heating due to the capture and reemission of stellar radiation; and heating due

to the capture and reemission of radiation from facing disk surfaces. The latter two components depend sensitively on the shape of the disk. Models that treat each disk annulus as a plane-parallel atmosphere suggest that the distance between midplane and photosphere of the disk at any given radius is largely determined by the opacity of material at the high-density midplane. A schematic profile of a low-mass flux disk is shown in figure 1. The reprocessing of radiation within the system is indicated by arrows.

In the inner regions, the disk is hot enough for dust to be destroyed at the midplane, and the disk thickness increases strongly with radius. In this region, the disk surface is strongly heated by radiation from both the luminous protostar and facing disk surfaces. At larger radii, where the disk is cooler, dust, which provides an additional source of opacity, is condensed throughout the atmosphere of the disk. In this region, the thickness of the disk increases more slowly, and stellar radiation cannot illuminate the surface. The transition between the two regimes occurs at approximately the present-day orbit of the Earth, suggesting that the outer planets formed under cooler conditions than would be expected if the disk were assumed to flare uniformly with radius.

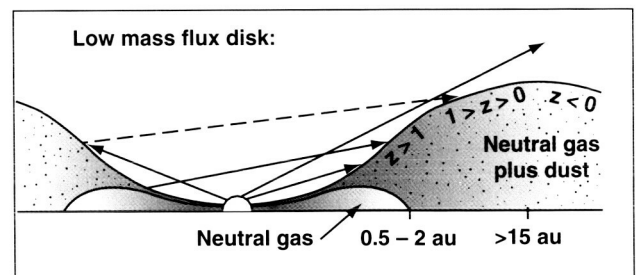


Fig. 1. A schematic profile of a low mass flux disk around a solar mass star. The trend of the disk thickness with radius, $H(r)$, is controlled by the local opacity. Note that $H(r)$ is proportional to r^2 . In the inner regions, the star illuminates the surface of the disk; at larger radii, the disk is in shadow.

Point of Contact: K. Bell
 (650) 604-0788
 bell@cosmic.arc.nasa.gov